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REPORT R-1627

THE ISOTHERMAL TRANSFORMATION CHARACTERISTICS OF
4330V (Mod + Si) STEEL

By

J. W. FORNEY

OMS Code 5520.11.43400.01
DA Project 50201008

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April 1962

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OF 4330V (Mod + Si) STEEL

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April 1962

ABSTRACT

The isothermal transformation characteristics of two heats of 433OV (Mod +Si) steel have been investigated by means of the metallographic method. Both heats are deep hardening, the hardenability being limited by the start of the bainite reaction. The isothermal transformation diagram indicates that this material may be suitable for ausforming, but not particularly suited to marquenching operations. The start of bainite transformation was found to vary within the compositional limits of the two heats of steel investigated. This would indicate that careful control of the composition would be necessary to achieve a high degree of uniformity of mechanical properties after heat treatment.

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INTRODUCTION

Since World War II, the increasing emphasis on lightweight weapon systems has necessitated the use of steels of higher yield strength than those used previously. Although present recoilless rifle steels have a yield strength of 165,000 psi, proposed designs require a steel with a yield strength of 200,000 psi and good toughness.

A preliminary evaluation of commercially available steels indicated that steels having adequate strength were deficient in toughness, while those with adequate toughness were deficient in strength.^{1*} Frankford Arsenal therefore developed a new steel, 433OV (Mod + Si), for use in recoilless rifles. Experimental work^{2,3} has shown that the mechanical properties of this steel meet the requirements of the recoilless rifle program.

To help plan improved heat treatments and to assist in the interpretation of microstructures observed in heat treated gun tubes, a study of the isothermal transformation characteristics of this steel was undertaken.

MATERIAL

Two heats of 433OV (Mod + Si) steel, from which experimental gun tubes had been fabricated, were selected for this investigation on the basis of their chemical composition. The compositions are shown in Table I.

*See REFERENCES

TABLE I. Composition of 433OV (Mod + Si) Steels

Heat No.	Element (Wt %)								
	<u>C</u>	<u>Mn</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Mo</u>	<u>Si</u>	<u>V</u>
21K631	0.34	0.98	0.005	0.015	0.95	1.82	0.42	1.37	0.14
21L482	0.31	0.91	0.006	0.013	0.94	1.77	0.44	1.43	0.10

These two heats represent the extremes in composition of the present commercially produced heats.

Specimens (1/4 inch square by 1/16 inch thick) were machined from the material. All specimens were plated with a 0.00025 inch thickness of nickel to prevent decarburization during subsequent heat treatments. They were then normalized at 1700° F for one hour and cooled in still air.

EXPERIMENTAL PROCEDURE

Decomposition of Austenite

The methods available for determining isothermal transformation are: magnetic, dilatometric, and metallographic. The results of this study were based solely on the metallographic method. This was preferred because it permitted study of the structure of the decomposition products in order to gain knowledge of the mechanisms of transformation.

As shown schematically in Figure 1, specimens for the study of the decomposition of austenite were heat treated (using the method prescribed by Davenport⁴) according to the following schedule:

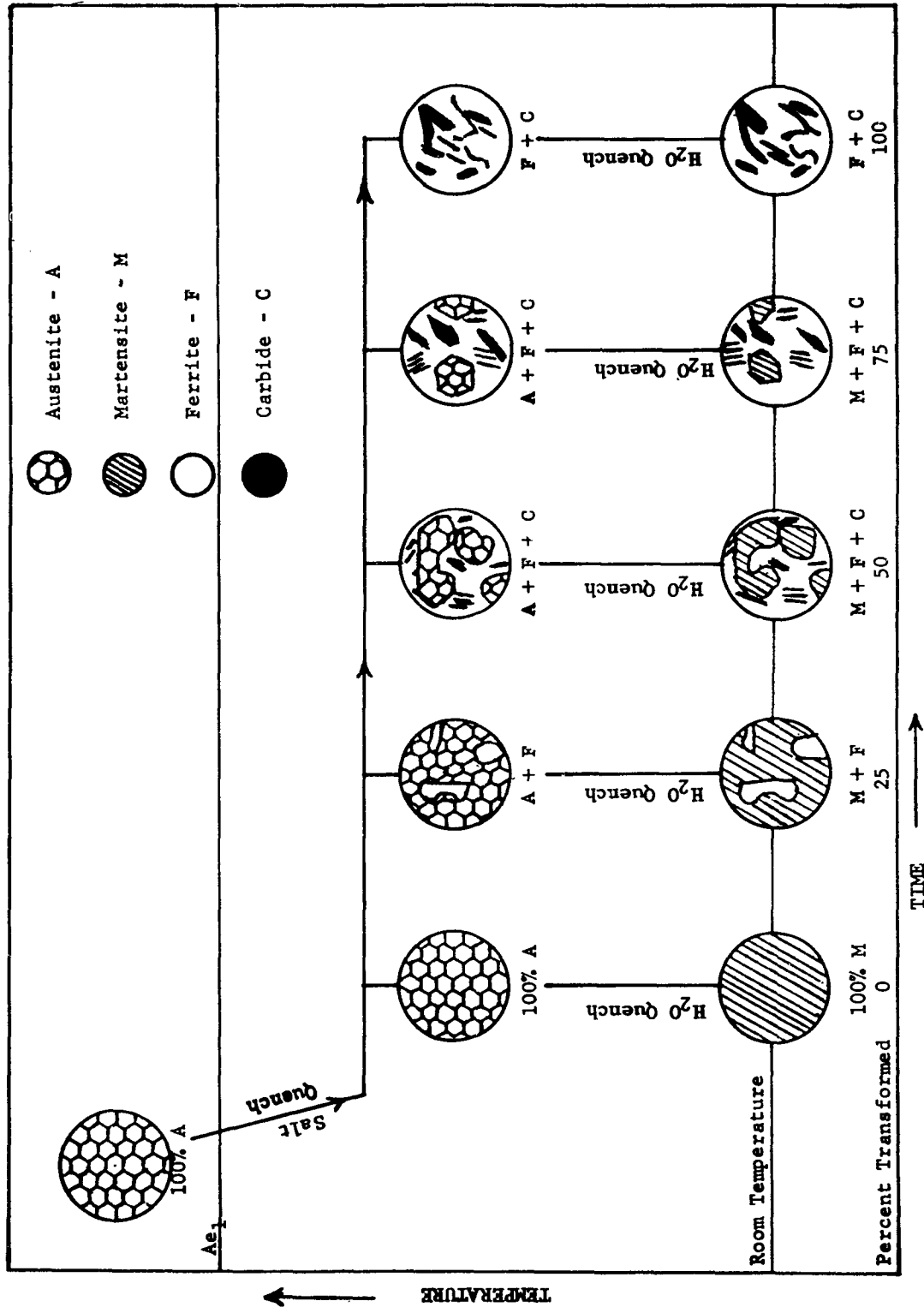


Figure 1. Diagram of Heat Treating Operations involved in preparing Specimens of 4330V (Mod + Si) Steel for estimating the progress of Decomposition of Austenite at Constant Temperature

1. Austenitized at 1650° F.
2. Transferred to molten lead bath maintained at the temperature of interest, and held at that temperature for a predetermined time period.
3. Quenched in cold water.

By metallographic examination, the amount and type of transformation products formed during the time in the lead bath could be estimated visually. It was assumed that any untransformed austenite remaining in the specimen at the end of this isothermal hold appeared as martensite after the final quench in cold water.

Equilibrium Temperatures

The lower equilibrium temperature (Ae_1) was determined by plotting two curves:

1. Temperature vs time to the start of isothermal formation of austenite from martensite, and
2. Temperature vs time to the start of isothermal precipitation of carbide from austenite.

As they approached each other asymptotically, the Ae_1 temperature was taken as halfway between these two curves at the point of their closest approach, within practical time limits (one week). Similarly, curves were plotted from which the upper equilibrium temperature (Ae_3) was determined. These curves were found from temperature vs time for the start of isothermal precipitation of ferrite below Ae_3 and the start of isothermal solution of ferrite above Ae_3 .

The treatment of these specimens for determining the equilibrium temperature was similar to that used in the study of the isothermal decomposition of austenite, with one exception - fully hardened rather than austenitized specimens were immersed in the molten lead bath to study the formation of austenite above the equilibrium temperatures.

Martensite Transformation

The technique used to determine the M_s temperature and to study the progress of martensite transformation was that developed by Greninger and Troiano⁵ and is diagrammed in Figure 2. As the diagram shows, the specimens were austenitized, immersed into a constant temperature bath at the temperature under investigation and held at temperature for a predetermined time, tempered for two minutes at 900° F, and quenched in water. The specimens were then examined metallographically.

If the temperature under investigation was the M_s or below, martensite formed in the austenite during holding. This martensite was darkened by the tempering operation, and the residual austenite was transformed to martensite by the final water quench. The martensite formed at the temperature being studied appeared as dark, tempered martensite in a matrix of light, untempered martensite.

RESULTS AND DISCUSSION

Decomposition of Austenite

The isothermal transformation diagram for both heats of steel is shown in Figure 3, together with the corresponding microstructures and hardnesses. Both heats had similar transformation characteristics at temperatures above 1000° F. The transformation was extremely sluggish in this region; however, this may be expected with this type steel. At the upper nose of the curve, near 1250° F, 30 minutes were required to incubate the precipitation of ferrite.

The upper portion of the isothermal transformation diagram suggests a method of preparing this steel for machining which results in a fine pearlitic microstructure. This treatment involves austenitizing, quenching to 1250° F, holding for 10 hours, and air cooling. This treatment results in a hardness of Rockwell C22. It

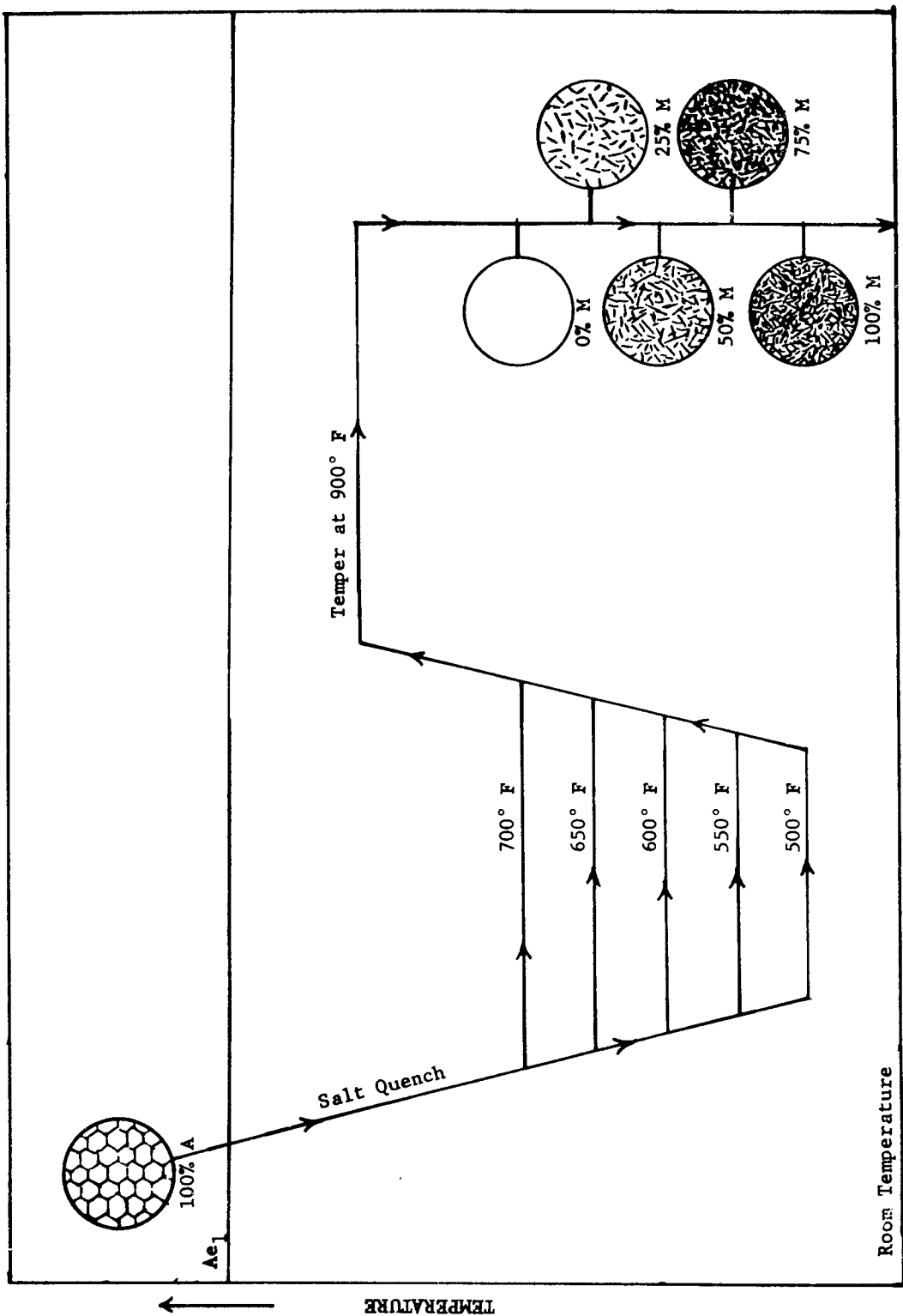


Figure 2. Diagram of Heat Treating Operations involved in studying the Martensite Transformation in 4330V (Mod + Si) Steel

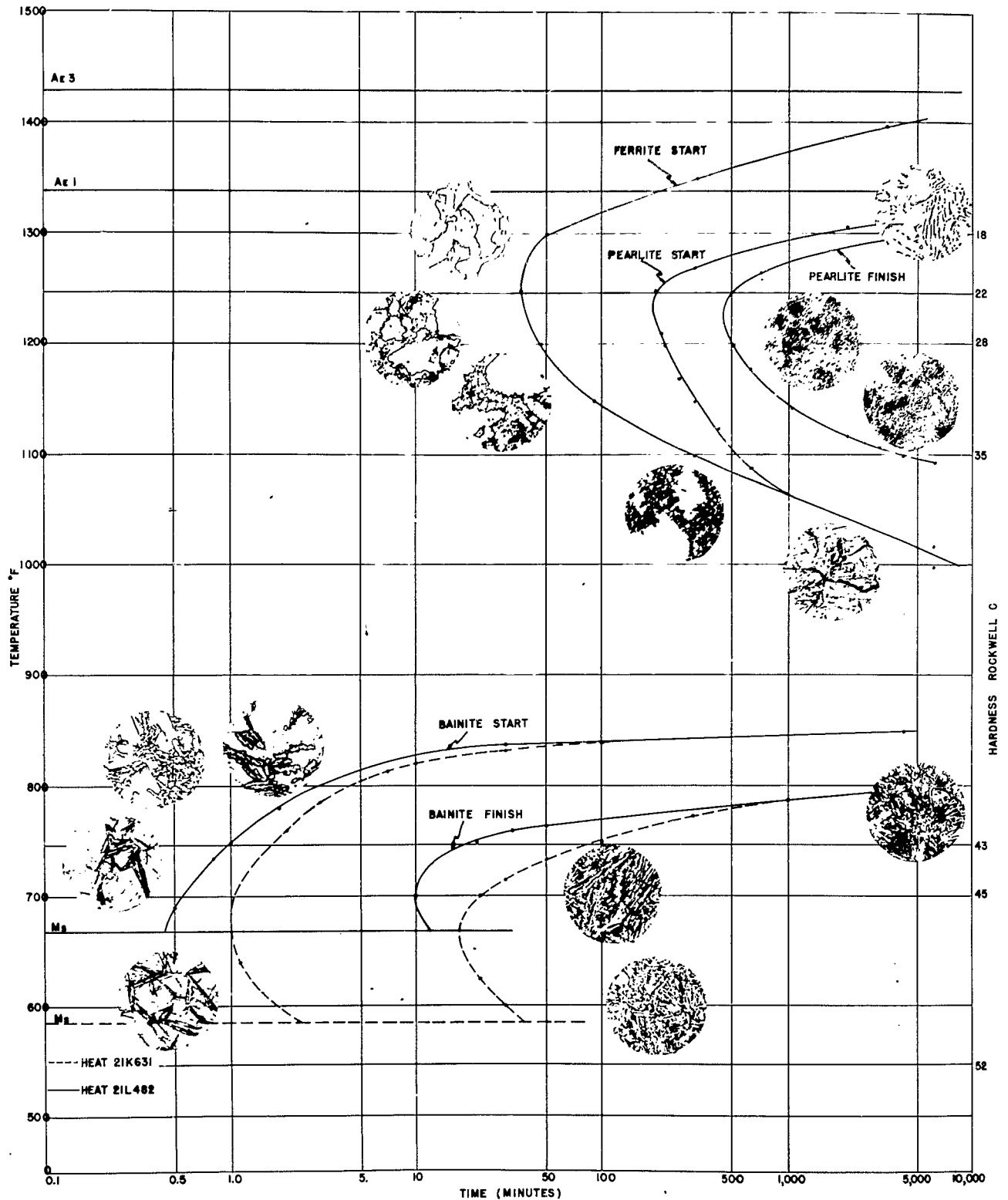


Figure 3. Isothermal Transformation Diagram for two heats of 4330V (Mod + Si) Steel, Austenitized at 1650° F (ASTM grain size No. 4)

should be applicable to fairly large cross sections because of the long holding time (30 minutes) available before transformation starts during cooling from the austenitizing temperature to the transformation temperature. Before this method would be acceptable, however, further work would be required to determine the machineability of the resulting structure.

After 5000 minutes at 1050° F, a small amount of transformation product appeared at the austenitic grain boundary, as shown in Figure 4. This product appears to consist of ferrite and carbides in a form generically similar to that of Davenport's X constituent.⁴

There was no indication of transformation after holding for 6000 minutes in the intermediate temperature range of 850° to 1000° F. The lack of transformation in this temperature range and the long incubation time in the upper portion of the curve make this steel ideal for ausforming.

At the lower temperatures of isothermal transformation, heat 21K631 was slower in transforming; also, it had a lower M_s temperature than heat 21L482. These differences in transformation rate and M_s temperature may be related to the variations in chemical composition of the two heats. The effects of the various alloying elements on the start of bainite transformation, as shown by Hollomon and Jaffe,⁶ indicate that the higher percentages of carbon, manganese, chromium, and nickel in heat 21K631 should result in a slower transformation to bainite. Thus, although the differences in composition of the individual elements of the two heats were relatively small, their combined effects may be clearly seen.

The early start of transformation to bainite at the lower temperatures limits the hardenability of the steel. Although martensite and lower bainite appear to have the same microstructure and hardness, the presence of lower bainite will result in the degradation of the mechanical properties in this steel, as shown previously.³ Since the hardenability is controlled by the bainite-start curve and since this curve may shift with small changes in chemical composition, the hardenability of this steel may vary significantly from heat to heat unless the chemical analysis is closely controlled. Further, it appears that this steel cannot be marquenched in heavy sections because the time to the start of transformation to bainite is rather short. In steels of this type it is usually desired to develop the full strength characteristics.

In general, all the microstructures found in this steel were similar to those found in most low alloy-high strength steels. A representative microstructure, formed on oil quenching from 1650° F, is shown in Figure 5.

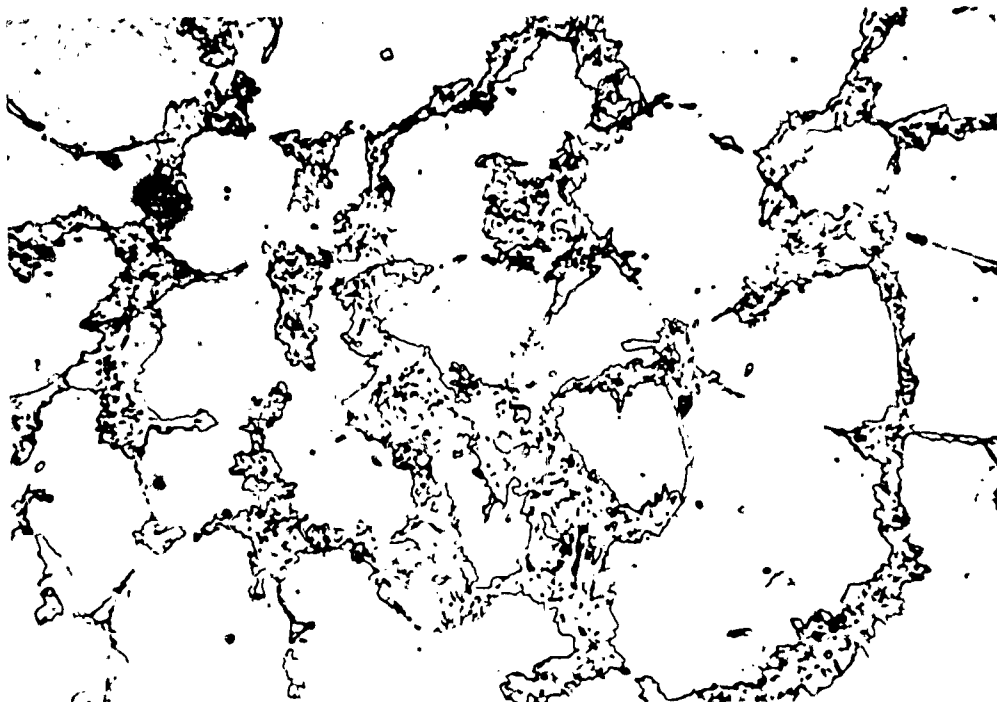
Critical Temperatures

The determination of the thermal equilibrium temperatures illustrated in Figure 6 gave an Ae_1 of 1337° F and an Ae_3 of 1428° F for heat 21K631. The equilibrium temperatures are necessary to complete the isothermal transformation diagram, but are not of great practical importance since most austenitizing is done several hundred degrees above the upper equilibrium temperature and most tempering is done several hundred degrees below the lower equilibrium temperature. Generally, it is not necessary to know the variation in the equilibrium temperature from heat to heat. Also, the upper portions of the isothermal transformation diagrams were similar for both heats. Therefore, the equilibrium temperatures were only determined for heat 21K631.

The results of the transformation-to-martensite study are shown in Figure 7. The reaction proceeds similarly for both heats, but at different temperatures. The M_s temperatures are 670° F for heat 21L482 and 585° F for heat 21K631. The reaction is a normal martensite transformation with a slow start and finish and a rapid transformation in the intermediate range.

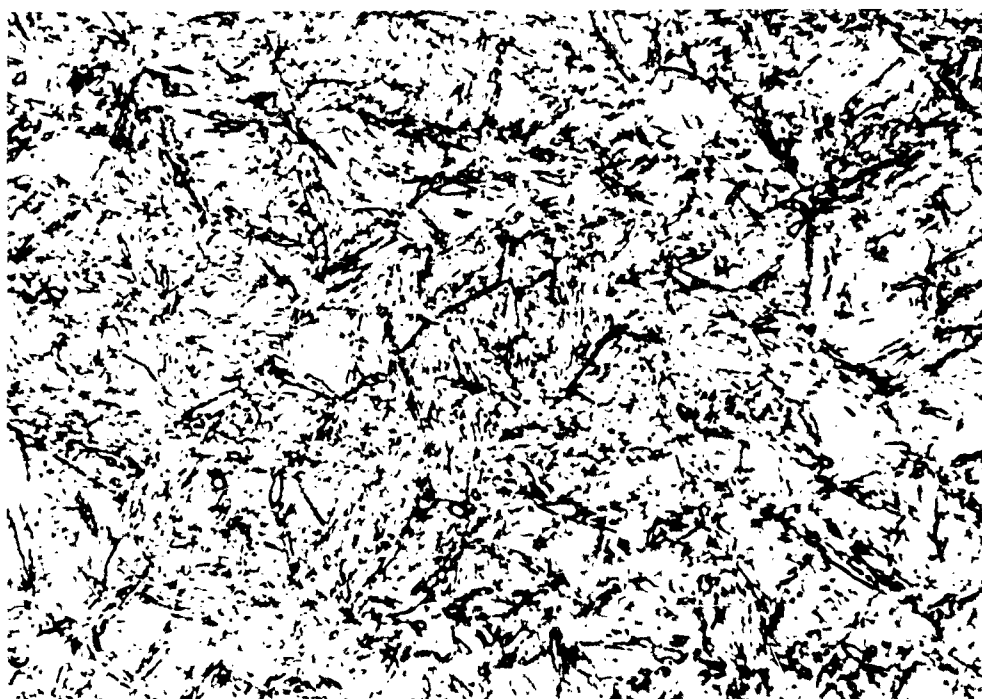
CONCLUSIONS

1. Isothermal transformation is sufficiently slow in 4330V (Mod + Si) steel in the high and intermediate temperature ranges to permit ausforming of this type steel.
2. Reaction time in the lower temperature range is too fast for this steel to be marquenched in heavy sections.



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Figure 4. Microstructure of 4330V (Mod + Si) Steel, Heat 21K631, Isothermally Transformed at 1050° F and held 5000 minutes



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Figure 5. Structure of 4330V (Mod + Si) Steel Austenitized at 1650° F, Oil Quenched, Untempered

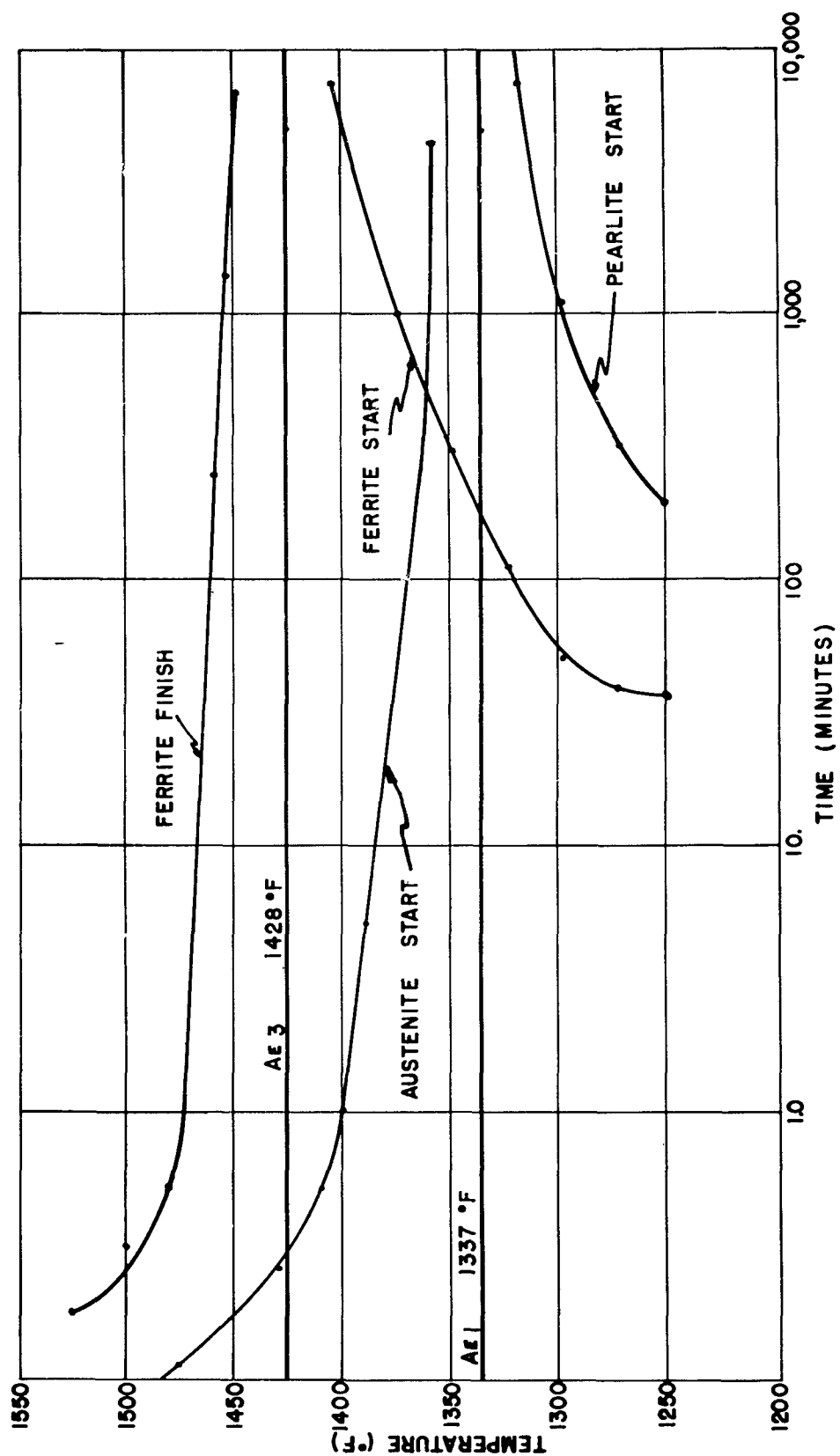


Figure 6. Determination of Equilibrium Temperatures of 4330V (Mod + Si) Steel, Heat 21K631

3. The rapid formation of bainite limits the hardenability of this steel.

4. Variations in the time to start the bainite transformation indicate that careful control of the chemical composition is necessary to insure uniform heat treating results.

RECOMMENDATION

It is recommended that ausforming of 433OV (Mod + Si) steel be investigated as a means of increasing its strength-to-weight ratio.

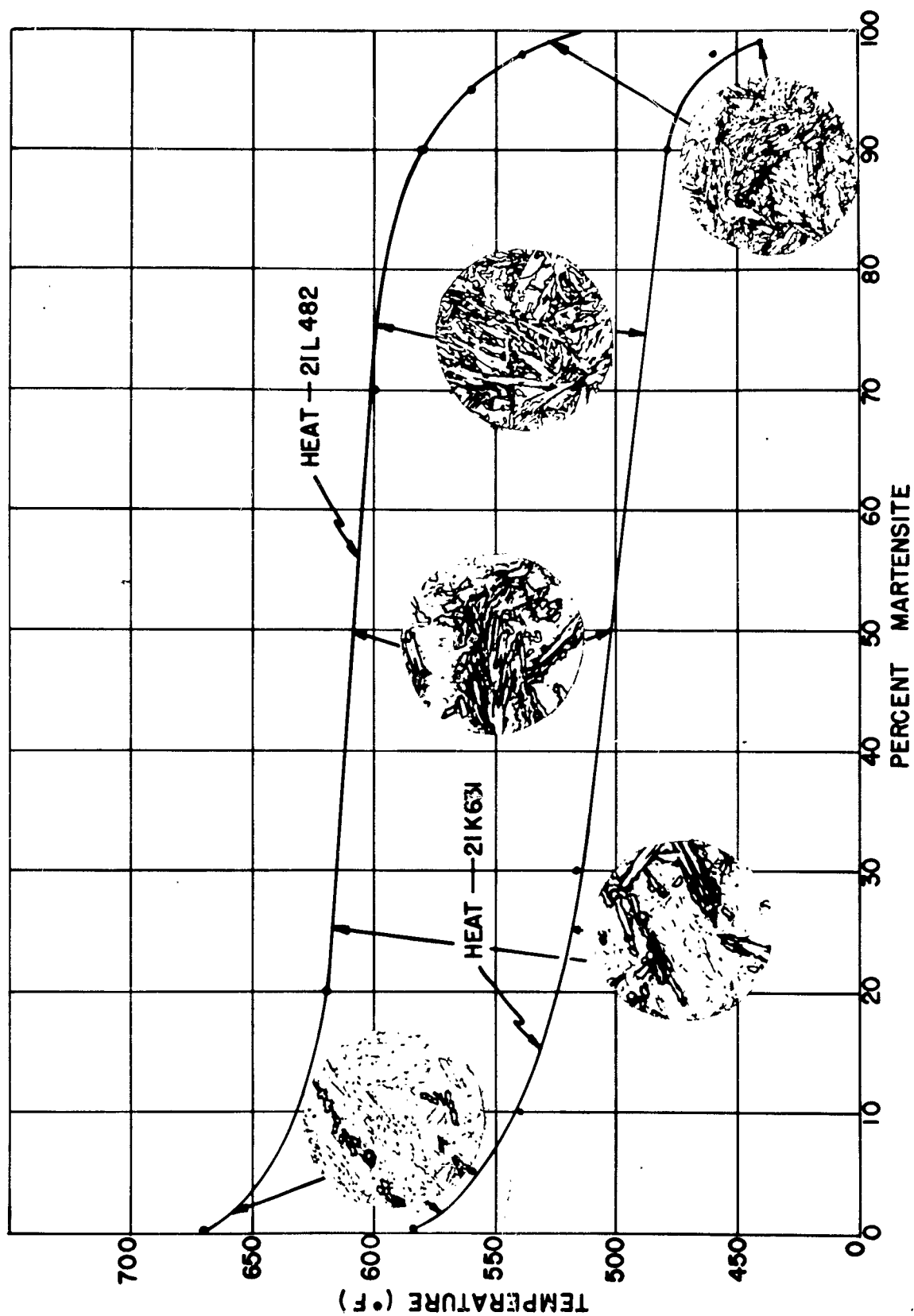


Figure 7. Progress of Martensite Reaction in 4330V (Mod + Si) Steel

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